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MANPOWER PLANNING AND PERSONNEL MANAGEMENT MODELS BASED ON UTIL--ETC(U)
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MANPOWER PLANNING AND PERSONNEL MANAGEMENT MODELS BASED ON UTILITY THEORY

by

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Abstract

The personnel management and manpower planning problems of the United States Navy include complex value structures with no obvious external criterion for examining alternative courses of action. Recognizing this, the Department of the Navy has sponsored studies of the applicability of utility theory to the personnel management and manpower planning problems of the Navy. The purposes of this project are to review and appraise such efforts and to recommend further work using utility theory to assist the Navy on manpower problems. It is concluded that the previous applications had numerous unnecessary shortcomings. The specific problems addressed were not clearly defined, and appropriate procedures to assess utility were not used. However, recommended applications of utility theory to manpower problems have the potential for significant contributions.

CONTENTS

1.0 THE MANPOWER PLANNING PROBLEM

The analysis of alternative plans to achieve the goals of management requires an objective function. Utility theory (see von Neumann and Morgenstern [1947]) provides a formal methodology to develop such an objective function. Utility theory includes procedures to quantify the value structure of management using professional value judgments. It is particularly helpful for those problems involving complex values where no external criterion (such as monetary profits) is appropriate.

The personnel management and manpower planning problems of the United States Navy do include such complex value structures with no obvious external criterion for examining alternative courses of action. Recognizing this feature, the Department of the Navy has sponsored studies of the applicability of utility theory to the personnel management and manpower planning problems of the Navy. This report reviews and appraises such efforts that have used utility theory, and recommends further work using utility theory to assist the Navy on these problems.

Quoting from Jaquette, Nelson, and Smith [1977], "The usual dichotomy between manpower and personnel assigns to manpower such job-related functions as the setting of manpower requirements, the specification of jobs or billets, and the determination of skill levels or other qualifications for personnel assigned to particular jobs. Requirements models calculate the types and skills of personnel required to meet certain operational objectives. These models are used, for example, in calculating training facility staffing requirements as a function of accessions, repairmen as a function of flying hours, and accessions requirements to staff the operating force. The personnel function includes hiring, advancement, retention, and other activities directly related to people. Training may be viewed as belonging to either manpower or personnel; in truth it belongs partly to both."

There are several important decisions which are part of manpower planning and personnel management. In the short-term static case, where the personnel levels and expertise are given, manpower planning essentially consists of assigning individuals to positions. However, perhaps the more important aspect of manpower planning concerns the impact over time and the change of makeup of the force over time. Many crucial personnel decisions affect this makeup such as the continuance policy, the advancement policy, and the recruitment and retirement policies of the Navy. If the manner in which Naval experience contributed to the overall performance of the Naval mission was better understood, decision makers would be better prepared to make responsible and more informed decisions about such policies.

Manpower planning and personnel management problems are very complex for several reasons. Perhaps the key reason is that the objectives are not at all clear on an operational level. At the overall level the objective is clear, to provide for the security of the nation and the best defense possible. However, what this means in terms of the number of people in the various positions, the amount of experience desirable for people in these positions, the particular distribution of experience to provide for defense over time, and personnel policies is not clear. Directly related to these questions is the important problem that even if the manpower and personnel objectives were clear, it is not obvious how they should be measured. This is further complicated by the fact that the value of a particular person in a particular job is not something totally independent of the individuals in related jobs. That is, there is a great amount of synergy between the value of an individual doing one job and the individuals who are doing related jobs. Simply stated, this says that many of the important functions of the Navy are done by teams. One person may be critical as part of a team, but operating as an individual, he or she may not be in a position to contribute very much.

1.1 The Task and Research Strategy

The task of this research is to review the manpower planning and personnel management efforts involving utility measurement. The review is meant to clarify exactly what decisions should be investigated using utility theory and what utility models have been developed to investigate those problems. The heart of the review is to discuss in detail what has been done and appraise that work. It will indicate clearly the strengths and weaknesses of the utility theory approach.

A literature search (see Appendix C) clearly indicated that the main work involving manpower planning and utility theory has been conducted through the Department of the Navy. Thus, the report carefully surveys these efforts. In addition, a key aspect of the report will be to suggest additional work using utility theory which may be productively undertaken to assist in Naval manpower and personnel decisions.

1.2 Previous Studies

Recognizing the difficulty in developing operational measures necessary for manpower planning and personnel management, the Department of the Navy has over the last few years supported studies in this area. Several studies performed by B-K Dynamics provided some initial estimates of an individual's utility to the Navy as a function of their length of service and their pay grade. These assessments were based on quantitative judgments elicited from Naval officers via questionnaires (B-K Dynamics [1973], Schmid and Hovey [1975]). As a complementary study to the B-K Dynamics work, Decisions and Designs, Inc. conducted a study to examine accrued utility to the Navy as a function of experience and pay grade distinguished for several different ratings and jobs performed in the Navy (Campbell, O'Connor, and Peterson [1976]). All of this work was aimed at developing procedures to determine the value of a particular type of individual performing a job. This is necessary in order for the Navy to maximize the cost effectiveness of its enlisted force. These position values then serve as inputs to the many models which have been

developed by the Navy to incorporate cost and effectiveness.

Also over the last several years, there have been other attempts to assist in manpower planning and personnel management for the services. Noted among these are some of the work done by the Rand Corporation (see, for example, Jaquette, Nelson, and Smith [1977]) and the Center for Naval Analysis (see, for example, Horowitz and Sherman [1977]). Most of these efforts did not explicitly use utility theory in the models.

1.3 Outline of the Report

The next chapter discusses the role of utility theory in manpower planning. It concerns both the conceptual problems of structuring the objectives and defining utility, as well as the operational problems concerning assessment of the utility function. Chapters 3 and 4 are devoted respectively to the work of B-K Dynamics and Decisions and Designs, Inc. Their work is briefly summarized and appraised. Chapter 5 recommends productive future work involving utility theory and manpower planning.

There are three brief appendices. Appendix A presents an overview of analyses that have been done to assist manpower planning and personnel decision making. Appendix B presents a summary of the work by Horowitz and Sherman [1977]. The approach is quite different from that of utility theory, but the goal is to get an indication of the overall personnel performance and its relationship to mission productivity. Hence, it seemed appropriate to indicate the general directions of this approach. Appendix C describes our literature search for the use of utility theory in manpower planning.

2.0 THE ROLE OF UTILITY THEORY IN MANPOWER PLANNING

Utility theory is a fundamental part of decision analysis. To examine the role utility might play in manpower planning decisions, it will be helpful to discuss an overview of decision analysis. This we will do and then move directly to discussing utility theory.

Decision analysis is a systematic and logical procedure, based on a set of axioms for rationally analyzing complex decision problems. These fundamental axioms are formulated in a slightly different manner in each of von Neumann and Morgenstern [1947], Savage [1954], and Pratt, Raiffa, and Schlaifer [1964]. Decision analysis is developed on the assumption that the attractiveness of alternatives to the decision maker should depend on:

- the likelihoods of the possible consequences of each alternative, and
- the decision maker's preferences for those possible consequences.

What makes decision analysis unique is the manner in which these factors are quantified and incorporated formally into the analysis of a problem. Existing information, collected data, models, and professional judgments are used to quantify the likelihoods of the various consequences. Utility theory is used to quantify preferences.

The decision analysis approach attempts to consider systematically all the available relevant information and to use explicitly the preferences of the decision makers. This is done by breaking the problem into parts which are easier to analyze than the whole, and then putting the parts back together in a logical fashion. The crucial difference between decision analysis and other approachs that claim to help the decision maker is that decision analysis provides theoretically sound procedures

for formalizing and integrating the judgments and preferences of experts and the decision maker to evaluate alternatives in complex decision problems. It is essential to exploit the experience, judgment, and knowledge of both professionals with training relevant to the problem and the individuals responsible for making decisions.

The decision analysis methodology can, for the purposes of discussion, be broken into five steps:

1. identifying objectives,
2. specifying objectives and attributes,
3. describing possible consequences,
4. evaluating consequences, and
5. analyzing and comparing alternatives.

The last step involves synthesizing the information obtained in steps 1 through 4 to evaluate and compare the alternatives.

In this chapter, we will focus on step 2 and step 4. These are the two steps crucial to utility theory. In Section 2.1, we will discuss the specification of objectives and attributes. Section 2.2 discusses the definition and use of the concept of utility. Section 2.3 summarizes the general methodology useful for assessing utility functions.

2.1 Specifying Objectives and Attributes of Manpower Planning Studies

Any methodology for manpower planning must specify objectives and attributes (i.e., measures of effectiveness) to measure the degree to which the objectives are achieved by each of the alternatives. The distinct aspect of the decision analysis approach is the degree of formality with which this specification is conducted. One can consider the procedure broken into the following three steps: (1) specifying general concerns of interest to the decision maker, (2) determining the objectives, and (3) defining attributes for each objective.

The starting point for specifying clear objectives is a list of general concerns. These basically indicate the reason why the decision maker is interested in the problem. Very likely, there will be a number of general concerns ranging over such topics as battle-readiness, cost of the force, morale, and productivity. The general problem facing the decision analyst is to responsibly structure these concerns and eventually end at a reasonable set of objectives and attributes for the problem. The process of doing this is essentially a creative one. There are, however, several aids which may be useful. Previous manpower studies and governmental or service guidelines should be of significant help in articulating specific objectives. At this stage in the analysis, it may be possible to elicit the opinions of many individuals not on the analysis team.

The desired result of the structuring of concerns is an objectives hierarchy. This objectives hierarchy should have broad objectives at the top and more detailed objectives further down. The lower-level objectives can be viewed as a means to the higher-level ends. These ends are closely related to the general concerns of the decision makers. Holes or gaps in the hierarchy can be identified and filled in by the following means-ends reasoning.

For each of the lowest-level objectives in the hierarchy, it is necessary to identify an attribute. This attribute includes a scale for indicating the degree to which the associated objective is achieved. Identifying an attribute is sometimes easy. For example, an obvious attribute for the objective "minimize manpower costs" is millions of dollars. However, it is much harder to determine the attribute for an objective like "maximize force productivity". This may require construction of an attribute specific for the problem under consideration. Procedures for doing this are discussed in detail in Keeney [1980].

In order to succinctly introduce the concept of utility, we must introduce some formal notation. Let O_i, i=1,...,n be n lowest-level objectives with the associated attributes X_i, i=1,...,n. Furthermore, define x_i to be a specific level of X_i, so the possible consequence of selecting a particular alternative can be characterized by the consequence $(x_1,x_2,\ldots,x_n)$. An example of the objective O_1 is "minimize force cost", and an associated attribute X_1 may be "annual cost in millions of dollars". A level x_1 could then be 193 million dollars.

In structuring the problem this way, we have addressed a number of complexities inherent in manpower planning decisions. First, it is clear that the procedure allows for multiple objectives, one identified by each O_i. The attributes provide a scale on which to assess the consequences of any alternative in terms of the objectives. For difficult to quantify concerns, such a scale can and must be constructed.

2.2 The Definition of Utility

A utility function is simply an objective function with some special properties. The objective function is a mathematical formulation of the value structure that the decision maker wishes to utilize in the problem. In many cases, objective functions are more or less assumed to be a given part of the problem structure. With utility theory, this is not the case. A great deal of effort is utilized to ascertain the specific value judgments which the decision maker wishes to have exhibited by his or her utility function. This information is elicited through interview techniques between an analyst and the decision maker. The utility function is assessed such that it is appropriate to use expected utility in evaluating alternatives involving uncertainties. Let us be more precise.

A utility function u is assessed which assigns a number u(x) to each possible consequence $x=(x_1,x_2,\ldots,x_n)$. The utility function has two convenient properties: (1) $u(x_1',x_2',\ldots,x_n')$ is greater than $u(x_1'',x_2'',\ldots,x_n'')$ if and only if $(x_1',x_2',\ldots,x_n')$ is preferred to $(x_1'',x_2'',\ldots,x_n'')$, and (2) in

situations involving uncertainty, the expected value of u is the appropriate index to evaluate alternatives. These properties follow from the previously mentioned assumptions of decision analysis first postulated by von Neumann and Morgenstern [1947].

2.3 Assessment of Utility Functions

For decision problems with multiple objectives, multiattribute utility theory provides the methods and procedures for implementing the concept of utility. The preferences of interest are always those with the decision maker or decision makers. They are quantified by asking the decision maker(s) several questions about value judgments desired to be utilized on the problem. The process of determining the utility function from these can be broken into five steps:

(1) introducing the terminology and ideas,
(2) determining the general preference structure,
(3) assessing the single-attribute utility functions,
(4) evaluating the scaling constants, and
(5) checking for consistency and reiterating.

For discussion purposes, each of these can be considered a specific step although in reality there is considerable interaction among them.

The general problem of structuring values is critical to the evaluation of alternatives in any decision problem. For structuring and assessing utility functions, several books have major parts which address evaluation in complex situations (see, for example, Fishburn [1964, 1970], Krantz et al. [1971], and Keeney and Raiffa [1976]). In the past decade, numerous articles have also appeared in the technical literature on this subject. Extensive recent reviews of this literature are found in Fishburn [1977] and Farquhar [1977]. Rather than repeat this information here, we will simply summarize the spirit of the approach. The general procedures used to assess a utility function involve subdividing the assessment

of u into parts, working on these parts, and then integrating them together. This requires that general qualitative value judgments of the client be stated and then quantified. The mathematical implications of these statements on the form of u are then derived.

As a simple example, consider the four-attribute case

$$u(x_1,x_2,x_3,x_4) = k_1u_1(x_1) + k_2u_2(x_2) + k_3u_3(x_3)u_4(x_4),$$

where u_i, i=1,...,4 are single-attribute utility functions, and k_1, k_2, and k_3 are scaling factors. Each of the corresponding X_i measures an objective. The k_i indicate value tradeoffs between the various objectives. This addresses the problem of how much of which objectives are more important than how much of which other objectives. The attitude of the decision makers toward uncertainty and risk is embodied in the assessment of each single-attribute utility function u_i.

Experience has indicated that a few general value assumptions seem reasonable for a broad class of decision problems. These assumptions imply a robust utility function which can be used to formalize widely different value structures. For any specific problem, the set of assumptions which appropriately define the decision maker's values must be identified to indicate which particular form of the utility function is appropriate.

The forms which follow from such assumptions require many value judgments to make them specific. These value judgments are the degrees of freedom, so to speak, which provide for the aforementioned robustness. Each focuses on one value question important to the problem, such as the value tradeoff between costs and productivity of the force. This provides the means of properly including these crucial value judgments necessary in manpower planning in a responsible, logical, and justifiable manner.

The decision analysis approach focuses on eliciting and clarifying the necessary information about values and expressing it in a form useful for evaluating alternatives. In addition, relative to other approaches there are three important advantages in structuring the objectives using a utility function:

1. the resulting models of value (i.e., utility functions) are derived formally and on a sound theoretical basis,

2. the procedures systematically elicit the relevant information about value tradeoffs and risk attitudes with the provision for numerous consistency checks to ensure accuracy, and

3. a sensitivity analysis of the decision maker's value judgments can be conducted.

In appraising the work of B-K Dynamics and Decisions and Designs in the next two chapters, we specifically examined whether or not these advantages were realized in the respective studies.

3.0 APPRAISAL OF THE B-K DYNAMICS, INCORPORATED STUDIES

This chapter first presents the general problem addressed by B-K Dynamics. Then Sections 3.2 and 3.3 present general and specific comments on the quality of the work from a utility theory perspective. Section 3.4 offers conclusions.

3.1 The Problem Statement

The general purpose of the B-K Dynamics studies [1973, 1975] was to develop procedures to assist in the evaluation of manpower planning alternatives for the Navy. The manpower planning alternatives which would be investigated included reenlistment policies, hiring and promotion policies, assignment rules, various innovative policies that would affect the manpower distribution within the Navy, and possible termination policies. The model developed was to be a part of an overall model for optimizing the Naval enlisted force.

In order to optimize, a quantitative index to indicate preferability is needed. Thus, it was necessary to develop a scale to indicate when one possible Naval enlisted force was better than another Naval enlisted force. The manner in which B-K Dynamics attacked this problem is as follows.

First, it was assumed that the desirability of a Naval force was equal to the sum of the desirability of the component enlisted men in that force. Each enlisted individual was identified by length of service (in years) and by paygrade. There were 31 categories for length of service, ranging from 1-31 years and 9 paygrade levels, referred to as E-1, E-2, ..., E-9. The study also differentiated personnel by their skill grouping initially, but this was found to be irrelevant for the optimization program.

As a result of the assumptions above, the B-K Dynamics problems boiled down to the requirement that the value of an individual with a

certain length of service and paygrade be specified. B-K Dynamics utilized various experienced Naval personnel to assign utilities to each combination of length of service and paygrade for the enlisted Naval personnel. Given the overall utility assigned, by aggregating over several individuals, and given the constraints* on an enlisted man's career, as described by length of service and paygrade, a model was developed to optimize the Naval force.

3.2 General Comments on the B-K Dynamics Studies

In this section we will summarize briefly the general problems concerning the use of utility in the B-K Dynamics model. These difficulties will be elaborated on in Section 3.3.

There are a large number of problems with the various aspects involved in the B-K Dynamics effort. First of all, the problem is not carefully defined. The weakest aspects concern the concept of utility as it is used in this study and the measures utilized to indicate desirability. The study relies heavily on what is referred to as the "average" man of a certain length of service and paygrade. However, this concept is never carefully defined and often loosely referred to in contradictory manners throughout the report.

The assessment procedures utilized to obtain utility estimates for various length of service and paygrade combinations were poor. In theory, there are many problems with the use of the Delphi procedure (see Sackman [1974]). However, in this study, it appears as if the theory was not followed carefully in the assessment. Thus, additional difficulties were introduced by the assessment procedure. The individuals utilized to obtain the assessments were also selected, it would appear, as much for

*Naval personnel must obviously enter in the first year of service and are usually in the lower paygrades. They then advance in length of service one year at a time until they decide to leave the Navy. They either maintain their paygrade each year or advance to the next highest paygrade.

convenience as other reasons. In particular, it would seem that they may not be representative of the overall judgments of Navy management.

Because of the difficulties above, it is difficult to interpret the results and implications of the study. To a large extent, the study itself does not produce any solid recommendations or refer to strong implications. However, if such were attempted, there would be little support for any recommendations because of the weaknesses of the study.

3.3 Detailed Comments on the B-K Dynamics Studies

In this section we will elaborate on the shortcomings referred to in the preceding section.

Problem Definition. A critical driving factor in any study aimed to produce an optimization model is to define the objectives to be achieved by the alternatives to be evaluated. The objectives for the Navy are never clearly outlined in the B-K Dynamics efforts. It is of course generally stated that the objective is to optimize the enlisted force, but little attention is focused on translating that general statement into terms more useful for the optimization model. In the technical literature, there has been a lot of attention focusing on the structuring of objectives. See for example MacCrimmon [1969], Raiffa [1969], Miller [1970] and Keeney and Raiffa [1976]. The use of some of the techniques for developing hierarchies of objectives may have made an important contribution to the B-K Dynamics effort.

In this study, it is directly assumed that the Naval force can be evaluated utilizing the sum of its individual components. That is to say, the value of the force can be calculated from the value of the individual men. This is a very strong assumption. No attempt is made in the study to justify the assumption or to investigate formally its appropriateness in the assessments.

There was another leap of faith made when the two attributes length of service and paygrade were chosen to characterize an enlisted individual in the Navy. It would have been much better if there would have been more justification for the selection. It may be possible that other attributes may better describe an individual such that the assessment could differentiate more clearly the value of that individual.* This difficulty is exacerbated by the use of the concept of the "average" enlisted man for each length of service and paygrade.

It is never clear what the utility of the average enlisted man serving at a given paygrade and length of service is to indicate. One possibility is that the utility would be for the value of an average person in that position for that one year. Another possibility is that it is the utility of an average person at that position considering what might possibly occur to that person in his remaining career in the Navy. That is to say, the utility is some sort of an average for the remaining career of an average individual. A third possibility is that the utility refers to the improvement from enlistment to the beginning of that length of service and paygrade by an average enlisted individual. This is more or less the accrued concept of utility referred to on page 3 of B-K Dynamics [1975]. Furthermore, does the average refer to a mean or a median or some modal type of individual? Nowhere in the study was this concept of average clearly defined, nor was it verified in the assessments of utility which followed. It seems very possible that different individuals could have widely different ideas on what the average meant.

A major fundamental weakness in the B-K Dynamics effort is that the concept of utility is never carefully defined. Unfortunately, perhaps, the term utility has several different meanings in the technical literature. To many economists, it is simply a function which ranks various

*In fact, the Decisions and Designs, Inc. study discussed in Chapter 4 indicates that the individual's rating (i.e., job) may be an important attribute to specify the value of an enlisted man.

commodity bundles (corresponding to the description of length of service and paygrade in this case) such that preferred commodity bundles are assigned higher utilities. Sometimes such a utility is referred to as ordinal utility, and the function which assigns it is referred to as an ordinal utility function (see Koopmans [1960]). Another use of the term utility is for a function which has cardinal properties, but which is not necessarily appropriate for use in evaluating alternatives where there is uncertainty about the consequences of each alternative. Recent papers on the "measureable utility", which include many previous references, are Dyer and Sarin [1979] and Bell and Raiffa [1979].

A third concept of utility, the one utilized by decision analysts, is introduced in Chapter 2 and is based on axioms such as those defined by von Neumann and Morgenstern [1947]. Subject to the appropriateness of such assumptions, a utility function exists with the property that it is appropriate to maximize expected utility in cases involving uncertainty about the consequences of the alternatives.

The B-K Dynamics effort never makes it clear exactly what utility is being used. Because the optimization is being done for alternatives which do not involve uncertainty, any of the various kinds of utility functions would have been appropriate for the model. However, the appropriate assessment procedure would differ depending on which type of utility functions were to be used. And of course, the procedure could affect the appropriateness of the resulting utility function for the use for which it was designed.

Utility Assessments. The assessments in the study were conducted in three parts. First, a Delphi experiment was performed using a senior officer panel and a junior officer panel from the Bureau of Naval Personnel. All of these officers had recently completed operational fleet assignments, which provided an opportunity to observe many individuals in various

positions in the Navy. These assessments attempted to determine utility functions for the average Navy enlisted man as he advanced in years of service. In addition, estimates of the utility for each paygrade regardless of the length of service were assessed. This implicitly makes either the assumption that the length of service does not affect the utility of an individual if you know their paygrade or the assumption that the assessee can average over all possible lengths of service to provide a reasonable answer. Both assumptions seem very hard to justify. The utility functions were simply sketched in by the participants and so it is not at all obvious what interpretation can be given them. However, because this Delphi experiment was not particularly significant in the study, no further comments seem necessary.

The second assessments conducted were done utilizing a questionnaire. The respondents involved senior enlisted men and students at the Naval Post Graduate School. Operational experience is needed to evaluate individuals at various lengths of service and paygrades. This need is referred to on page 14 of B-K Dynamics where it states "...the only practical source from which a measure (of utility) might be constructed were Navy experts--those who have had an opportunity to monitor the progress of the enlisted man and to observe the change in his usefulness to the Navy throughout his career." The senior enlisted men may very well have had the experience necessary for these assessments. It seems unlikely that this would be the case for the students.

When assessments of utility are carried out via questionnaire, there is always a major possibility for misinterpretations. Because of the difficulties in identifying the length of service and the paygrade of individuals by observation of the individual's performance, aggregation procedures were utilized for both measures in this questionnaire study. The length of service was categorized into first-termer, second-termer, careerist through 20 years, and careerist from 20-30 years. The paygrade

scale was effectively replaced by a rate grouping scale. This was categorized as apprentice, journeyman, and supervisor. Utility was not directly assessed, but proxies for utility were utilized in this study. The study used base pay, bonus pay, and achievement in terms of military ability, leadership ability, and professional/vocational ability.

First, for each combination of experience and rate, relative pay was assigned by the participant assessee, and this was used as a reflection of utility. A major unjustified assumption here is that utility is linear in the dollar values assigned. One would expect that many of the assessees may not feel that utility is linear in dollars and consequently the assessments would not reflect utility.

It appears that the assessees felt that the utility of various individuals as assigned by the basepay procedure closely reflected current pay. Because this judgment did not seem to be accepted by the study team, they decided to repeat the experiment using bonus pay. In this part of the experiment, a bonus pay of $100 was assigned to the experience and rate combination felt to be the best. Smaller bonuses were assigned to the other groups relative to this. The results turned out different from those previously assigned and seemed to be more accepted to those conducting the study. A major problem here was the fact that a $100 is a small amount of money, and experience suggests (see Schlaifer [1969]) that utility assessments should involve meaningful differences in the consequences. The fact that the difference in bonus pay between $100 and $70 may not be meaningful could have a detrimental effect on the validity of the results obtained from this experiment.

In the assessments involving achievement, there was an attempt to develop a three-attribute utility function for military ability, leadership ability, and professional/vocational ability. First, the importance of each of these three attributes for the three rates (apprentice, journeyman, and supervisor) were directly assigned. All the errors in such

direct importance assignments discussed in Keeney and Raiffa [1976] were made in this assessment. Next, the degree to which the various experience groups measured up in terms of these three attributes was directly specified. From this, the utility of each experience and rate combination was assigned. In these assessments, the implicit assumption was made that the utility for any experience grouping was independent of the rate. Such an assumption does not necessarily seem justified.

In the three preceding questionnaire experiments, a major assumption was necessary to relate rate groups and experience groups to paygrades and length of service. Using the relationships in Table 3.1, utility functions were assigned for paygrade and length of service combinations. With all of the assumptions necessary in this questionnaire experiment to reach this point, there is a considerable question about the interpretation of any results.

Table 3.1

Relationship of Rate and Experience Groups
to Paygrade and Length of Service
(From B-K Dynamics [1975, page 34])

Rate Groups	Equivalent Paygrade
Apprentice	E-3 and E-4
Journeyman	E-5 and E-6
Supervisor	E-7 through E-9

Experience Groups	Equivalent Length of Service (LOS)
1st termer	1-4 years
2nd termer	5-9 years
Careers with less than 20 years	10-20 years
Careers with 20-30 years	21-30 years

Finally, a third experiment referred to as Delphi II was conducted. In this experiment, the individuals whose values were assessed were officers

and senior enlisted personnel serving in the second fleet. Because all these individuals presumably have somewhat similar experiences, there is the obvious question about the appropriateness of their collective judgments for evaluating Naval personnel management problems. It may be that they have a systematic bias. The Delphi II experiment assessed the utility of an average enlisted man as he progressed in years of service while remaining at a specific paygrade. This was done first on a 0-100 scale for each paygrade. In order to do this, the number of years necessary for an individual to reach his maximum value and the number of years he remained in that maximum value were assessed. Then his value at the end of his service relative to his maximum value was assessed. And his value at entrance to the service was determined using a proxy related to the direct procurement petty officers program for entering the service at various paygrades. Finally, a judgment was necessary to relate the maximum value obtained by an average enlisted man at each paygrade relative to all other paygrades. A set of these curves resulting from the final round of the Delphi procedure is illustrated in Figure 3.1. A smoothing assumption was made to provide the continuously differentiable paygrade and length of service utility curves of Figure 3.2. These smooth curves were then utilized in the optimization model.

In addition to all of the problems mentioned earlier with interpretation, the assessment of the utility functions was not done well. First of all, no effort was made to determine the qualitative attitudes which the curves should reflect. For instance, no attempt was made to examine concavity or convexity properties as implied by risk averse attitudes (see Pratt [1964]) or by various strength of preference attitudes. In addition, the concept of zero utility was not clearly defined. This is important because the assessments implicitly assumed a zero value in setting up relative value as a percent of full value. There were no consistency checks provided for the several utility curves. For instance, from Figure 3.2, one can see that an individual in paygrade E-5 after 10 years should have the same utility as an individual in paygrade E-6 after

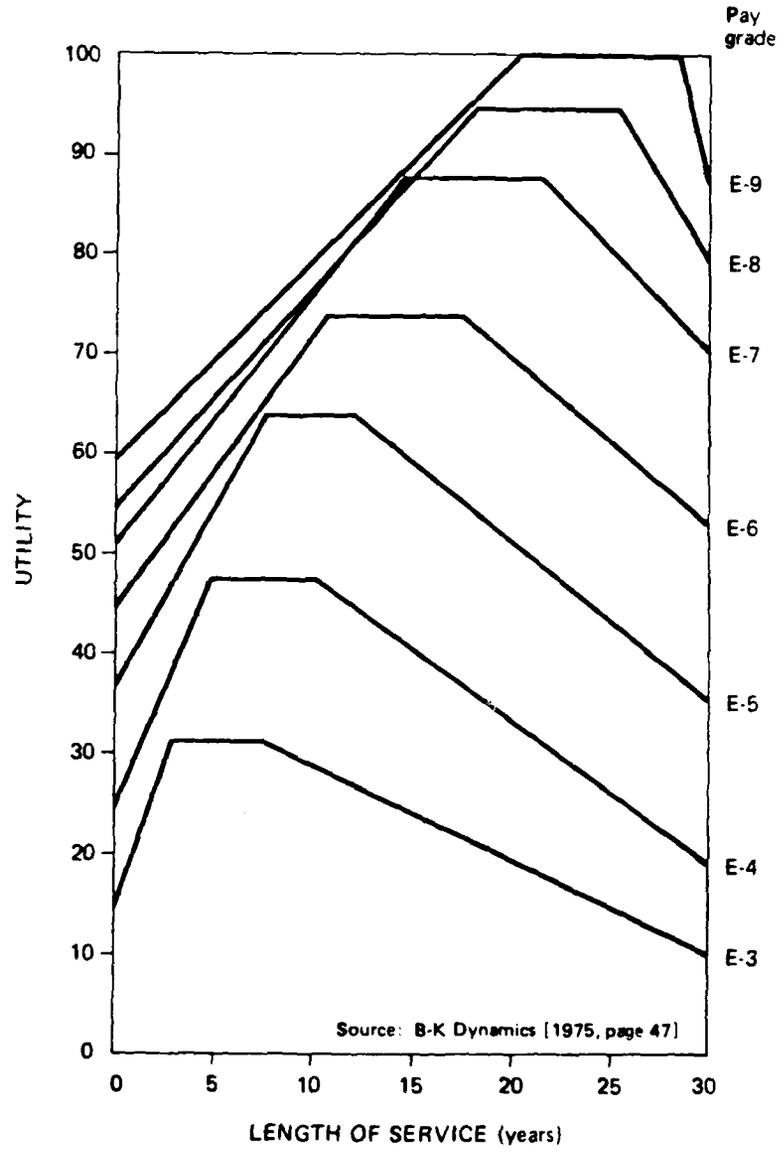


Figure 3-1. DELPHI II FINAL UTILITY ASSESSMENTS CURVES

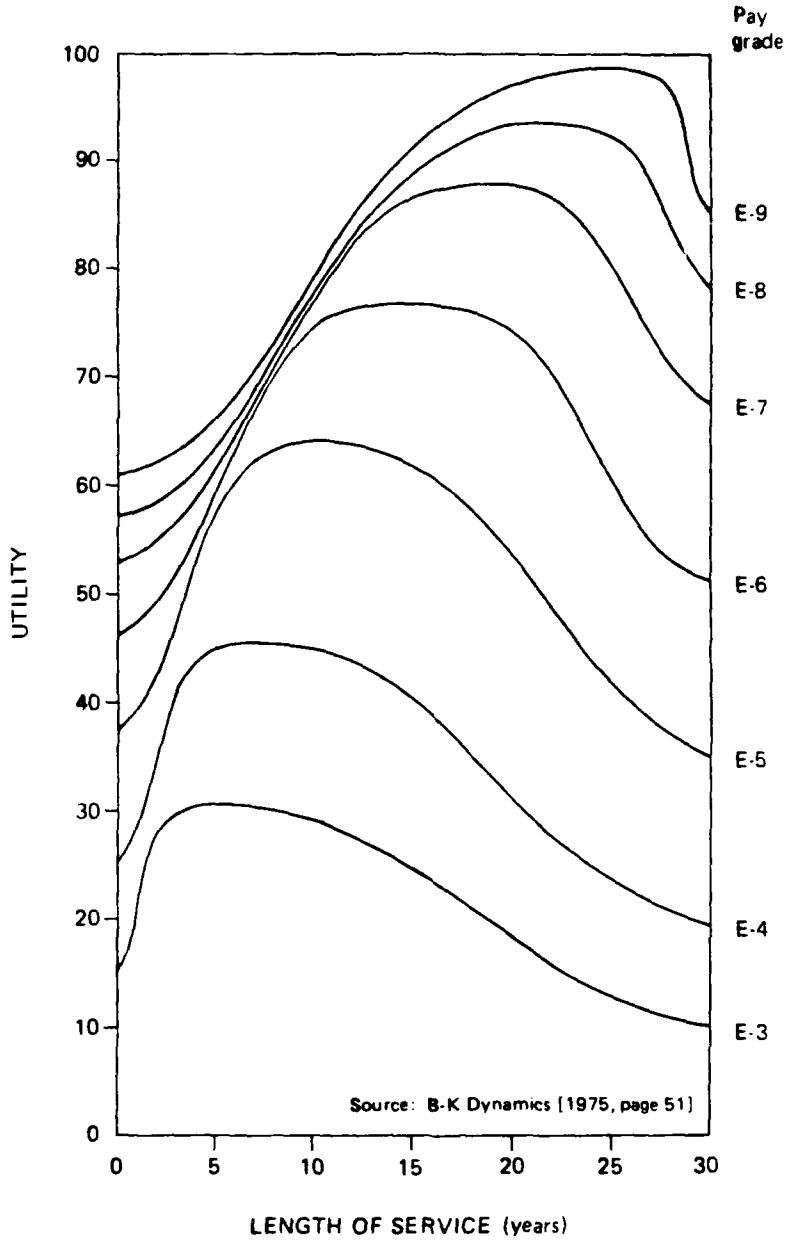


Figure 3-2. CONTINUOUS UTILITY CURVES

24 years. It would have been easy enough to check the validity of these assumptions with individual assessees.

Perhaps the biggest shortcoming of all in these studies is the fact that the results were averaged over all of the individuals being assessed. No attempt was mentioned to justify such an assumption. There have been many formal systems discussing how judgments of various individuals should be combined. For instance, see Arrow [1951], Harsanyi [1955], Sen [1970], Fishburn [1973], Keeney and Kirkwood [1975], and Keeney and Raiffa [1976]. In many of these references, the stringent assumptions required to simply average over individuals are mentioned.

3.4 Conclusions and Recommendations

Because of all the shortcomings in defining the problem and assessing the utility function, it is very difficult to conclude exactly what the utility function is meant to represent. In theory, as given in the problem statement, it is meant to indicate the value of an average person with the stated length of service and paygrade description. Then, by averaging over the distribution of individuals in each combination of paygrade and length of service, an optimal force can be obtained. However, since very little effort was made in relating any of this to the function of the Naval force, no substantial conclusions about better force distributions or better policies are justified.

For evaluating the optimal force, the B-K Dynamics study utilized the minimum cost/benefit ratio. In addition to all the assumptions in determining the utility function, the use of the ratio of costs to benefits also require substantial assumptions. A more general representation using costs and benefits or measures would be a utility function with arguments of costs and benefits. Then a two-dimensional value structure could be formulated using any of several models available as discussed in Fishburn [1965, 1970] and Keeney and Raiffa [1976]. Assumptions appropriate for

these models should be verified with individuals in positions responsible for making such decisions. Nowhere in the report was it even mentioned that assumptions were necessary to use the cost/benefit ratio criterion.

In summary, from the point of view of the utility model utilized in B-K Dynamics work, there is very little positive that can be said. There is also very little which could constructively be utilized in an optimization model meant to provide evaluation of strategic manpower planning options. It would appear to be better to start again and carefully define the problem and appropriately develop an optimization model than it would be to try build upon the B-K Dynamics work as a base. In this regard, the main contribution of the B-K Dynamics study is an example of things not to be done.

4.0 APPRAISAL OF THE DECISIONS AND DESIGNS, INCORPORATED STUDY

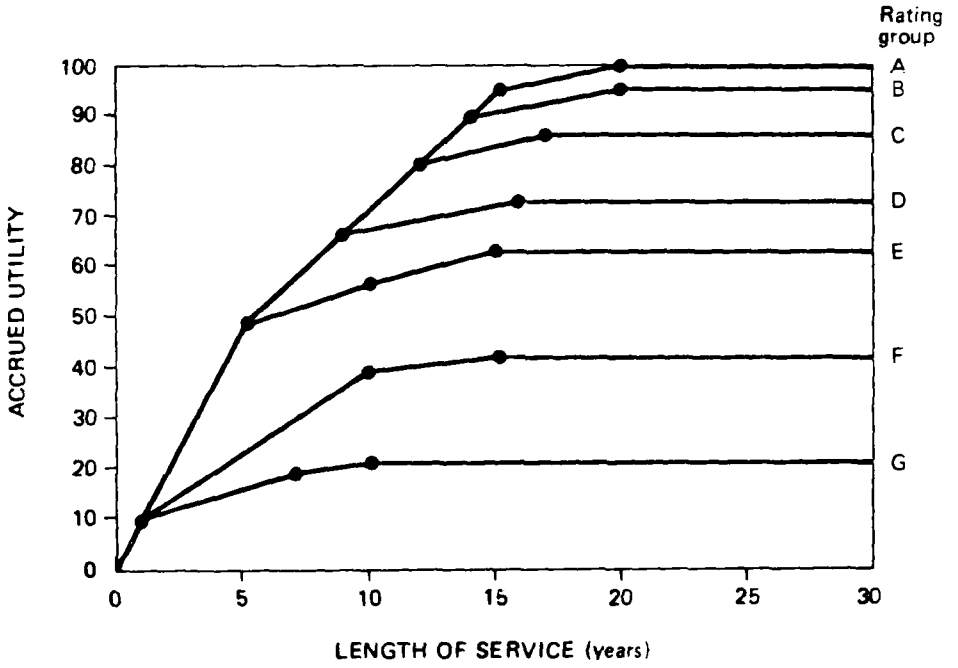
This chapter first summarizes the general problem addressed by Decisions and Designs, Inc. The work is then appraised.

4.1 The Problem Statement

The basic objective of the Decisions and Designs effort (Campbell, O'Connor, and Peterson [1976]) was to determine the relative contribution to Naval missions of the accrued utility relative to an initial reference at the beginning of apprenticeship. In particular, the percent of accrued utility as a function of length of service and paygrade were determined for seven rating groups. These rating groups were constructed based on judgments of experienced Naval personnel in the course of the utility assessments. Each group consisted of several specific ratings felt to be similar with regard to the rate at which accrued utility occurred as a function of length of service and paygrade.

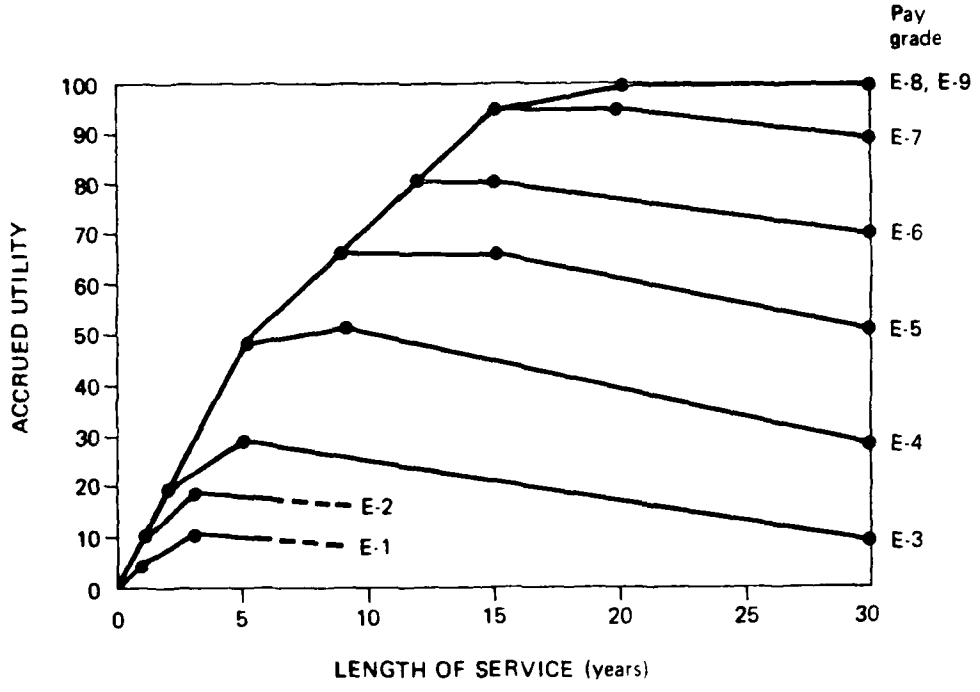
The utility assessments were carried out in individual interviews with 13 individuals with a range of experience in the Navy. This included four enlisted men and nine officers. In addition, judgments were obtained from several other retired officers of the Navy.

The results indicated the accrued utility for individuals as a function of length of service for each of the rating groups and at various payrates within the rating groups. The relative accrued value of the rating groups over time with respect to length of service is indicated in Figure 4.1. The A curve is for the most technically sophisticated of the rating groups. It assumes that the person in that group progresses over time by making all of the normal paygrade promotions. Thus, in a sense, this is the leading edge representing the accrued utility of a "rapid advancer" through the ranks. Figure 4.2 indicates the accrued utility for individuals in Rating Group A as a function of length of



Source: Campbell et al. [1976, page 23]

Figure 4-1. ACCRUED UTILITY ADVANCERS, AS A FUNCTION OF LENGTH OF SERVICE, FOR SEVEN RATING GROUPS



Source: Campbell et al. [1976, page 27]

Figure 4-2. ACCRUED UTILITY BY LENGTH OF SERVICE AND PAY GRADE FOR RATING GROUP A

service and paygrade. At the lower paygrades, the individuals are simply passed over for promotions and left behind.

It is evident from Figure 4.1 that there is a large distinction in accrued utility for various rating groups. From Figure 4.2, it is clear that there is also a large distinction within the rating group based on the paygrade one has achieved. This is not to be interpreted, however, as indicating that increases in paygrade causes increases in accrued utility. In fact, it is more likely that the paygrade increase is a recognition of the fact that the individual has achieved a higher level of accrued utility in the rating group.

In a sense, the Decisions and Designs effort was meant to build upon the B-K Dynamics work. Because of the major shortcomings of the latter, there were necessarily some major difficulties in using that as a basis. To a large extent, none of the data or procedures of the B-K Dynamics effort were utilized in the present study. However, the choice of using the length of service and paygrade as indices upon which to base accrued utility was utilized. The differentiation of accrued utility by rating group was certainly an improvement over the previous study. Also, although there are serious weaknesses in the assessment procedure of the Decisions and Designs work discussed below, in general the procedures were better than those utilized in the B-K Dynamics work.

4.2 General Comments on the Decisions and Designs Study

It appears as if there are two main shortcomings which one can ascribe to the Decisions and Designs work. The first deals with definition of the problem itself and the second with the assessment procedures used.

The main deficiency in the problem definition is that no attempt is made to relate the indices used in this study (namely the rating group, the length of service, and the paygrade) to performance of the overall Naval mission. It would not be necessary that this link be made quanti-

tatively, but a clearer definition of that link would be useful. Even without that link, there is little discussion to support the choice of these indices as a basis for the assessment of accrued utility. These indices may in fact be reasonable, but no justification is given.

The general Decisions and Designs procedure of using more in-depth interviews with a few individuals seems reasonable. However, although the report states that the individuals assessed did have a variety of experience in Naval positions, it is difficult to ascertain whether or not their experiences are in some sense representative of Naval experience. It is also difficult to ascertain whether this experience is appropriate for presenting the judgments necessarily made in this study. The report stated that the assessments were relevant to a battle-ready scenario. Although it is recognized in the report that there are other scenarios, and some rough assessments were done with regard to these, it is difficult to appraise the relevance of this scenario to the overall mission of the Navy. Again it would seem like this may be justified as a first-cut, but this point of view is not strongly supported in the report.

The major shortcoming with the assessments dealt with the fact that much of the information was not quantified directly from the individuals assessed. In fact, the quantification was done by the analysts based on their understanding of qualitative statements made by interviewees. The state of utility assessment is advanced beyond this, and there are more precise ways to ascertain the appropriateness of assumptions being made by the interviewees and the precise value statements they wish to make. As the authors have stated, there are difficulties in interpreting exact numbers. There are obviously going to be small amounts of error in any situation. However, this error can be greatly magnified when qualitative judgments of one individual are the basis for quantitative judgments of another.

4.3 Detailed Comments on the Decisions and Designs Study

This section will discuss in detail various aspects of the Decisions and Designs effort. It will be divided into three subsections dealing with the problem definition, the assessment procedures, and the interpretation of the results.

Problem Definition. In a narrow sense, the problem definition in this study was well defined. To quote from the summary of Decisions and Designs (Campbell et al. [1976]), "The purpose of this study is to determine the relative contribution to Navy missions of the accrued experience of enlisted personnel. For each Navy rating, the utility of a person with a particular length of service and a particular paygrade is examined. The methodology employed consisted of in-depth interviews and detailed justification for the utility functions obtained." The basic difficulty with this is that the relationship of individuals in various positions to the performance of the Naval mission was essentially never discussed. This seems like a crucial part of the problem which deserves some focus of the attention.

Effectively, this study obtained a utility function for the accrued utility of an individual in the Navy as a function of three attributes: rating group, length of service, and paygrade. More study should be done to justify the choice of these attributes as their choice implies strong value judgments. Other than the fact that the latter two were utilized in the B-K Dynamics study, essentially no justification is given. In the former case approximately 60 ratings were aggregated into seven rating groups based on judgments of the interviewees. The manner in which these judgments were made is never clarified. One thing that is clear from the study is the relationship between the accrued utility of an individual in a position with a certain length of service and paygrade and the total utility of the individual in that position. As stated in the report, "the total utility can be divided into two parts: the contribution a person can make to Navy missions when he or she first enters the job,

and the additional contribution (accrued utility) which he or she can make as a result of latter training and job experience. The point in time dividing these two parts of total utility is defined for this study as the start of apprenticeship."

As discussed in the preceding chapter, the term utility has many interpretations. In this study, as in the B-K Dynamics study, the interpretation utilized is never defined, nor is it clear from the context of the work. It could possibly be a von Neumann-Morgenstern utility function, or alternatively what is sometimes referred to as a value function (Keeney and Raiffa [1976]). If it is a value function, then it is not clear whether it is meant to incorporate the strength of preference or whether it is simply an ordinal ranking of that preference (see Dyer and Sarin [1979]). In some studies, the type of utility used could be ascertained from the assessments. However, in this case because the assessment procedures are not made explicit, one is left in the dark with respect to the definition and type of utility meant to be used in the study.

Assessment Procedure. In general, it seems as if the number of individuals utilized as interviewees in this study was very appropriate. However, it is difficult to determine if they had the experience appropriate for the purpose to which the study would be put. It would appear as if they did since the conclusions were quite general and were meant to provide only insights. Nevertheless, it seems as if the number of individuals with personnel planning backgrounds were over-represented. This is perhaps understandable because a personnel organization was funding and was interested in the results of the study, as well as personnel people now have the responsibility for making personnel decisions based on factors such as "accrued utility" of the individual.

The use of individual interviews in this study seemed very appropriate. This is a significant improvement over the B-K Dynamics work, especially

because studies such as these are partially experiments in the formative stage of problem definition. The quality of information obtained by direct interviews is likely to be significantly higher than the information obtained by indirect means such as questionnaires. The initial information obtained in the interviews also seems very appropriate. It concerned the background of the interviewee and their qualitative reasons about how experiences accrue throughout a career and a particular rating.

The shortcomings in the assessment procedure came when specific judgments were required about accrued utility. Relatively standardized utility assessment procedures such as those discussed in Schlaifer [1969] or Keeney and Raiffa [1976] were not used. Rather, general qualitative statements were expressed by the interviewees, and the analysts used the information to quantify what they perceived as the judgments of the interviewees. The manner in which this translation was made was not at all clear. To quote from Decisions and Designs (Campbell et al. [1976, page 36]), "The derivation did not utilize a mathematical formula for at least two reasons: first, interviewees often gave estimates only in verbal terms (for example, 'utility declines gradually thereafter'); and second, the analyst gave greater weight to those judgments supported by convincing reasons. The derivation of utility estimates was therefore a complex and partially subjective process."

Most utility assessment procedures do want to rely partially on qualitative expressions of preference or judgment. However, these are meant to suggest the general shape of the utility function. The procedures do afford the ability to obtain quantitative judgments directly from the interviewee to specify a functional form of the utility function having those qualitative properties (see Pratt [1964]). The assessment procedure should have been designed to do this.

More importantly, a great amount of reliance is necessary on the analyst's ability to interpret the meaning of the interviewee. For instance,

it was the analyst who decided which reasons were convincing. It was the analyst who used subjective judgments to formulate the utility function from the expressed statements of the interviewees. This general methodology provides great latitude for serious misrepresentations.

The final shortcoming with the assessment procedure is the fact that the judgments of all 13 interviewees were combined. However, one is never told exactly how they are combined, nor given any reason for the manner in which they are combined. As referred to in the preceding chapter, there are a number of formal procedures for combining judgments of various individuals. Each rule of combination requires many professional and value judgments in itself, and these assumptions should be made explicit when deciding to combine individual judgments.

4.4 Conclusions

The conclusions and recommendations in this study were not strong, and they seem to be appropriate. This study states that the main purpose of the utility assessments is to gain some insight into what may be useful manpower planning policies. It further states that the specific policy implications, however, are beyond the scope of this study. In light of this, it seems as if the study does not overclaim the implications of the results.

One main finding of the study is that the total accrued utility varies greatly among different ratings. The main reasons for the distinctions were suggested as the amount of learning required to do the job properly, the requirements of the jobs to make decisions without assistance from manuals or more experienced personnel, and the consequences of possible errors in the decision making function.

Two other findings of the study were that utility accrued almost entirely in the first 15 years, and in the first ten years for less technical ratings. Furthermore, there was a strong relationship between the

paygrade and the accrued utility in any particular rating. Those in lower paygrades tended to have a lower accrued utility by a significant amount.

The appropriateness of these results obviously depends on the appropriateness of the problem definition and the assessment procedure. The difficulties with these were discussed above, and therefore the results must be interpreted accordingly. However, if we do accept that the utility functions derived in this study are reasonable, the conclusions drawn by the study seem reasonable.

5.0 RECOMMENDATIONS FOR FUTURE UTILITY THEORY EFFORTS

When utility theory is utilized to its maximum benefit on decision problems, it involves the careful conduct of three steps:

1. structuring the objectives and attributes for the problem,
2. structuring and assessing an appropriate utility function, and
3. evaluating alternatives using the utility function.

As is evident from Chapters 3 and 4, neither of the two major efforts to use utility theory in manpower planning have taken full advantage of the approach. Some of the reasons for this may result from constraints on the time or resources available for the respective efforts. Nevertheless, it would appear as if each study had major weaknesses which need not have existed.

In this chapter, we will try to outline three potential research studies which may provide significant insight to naval manpower and personnel planners. The three studies will correspond to the three steps mentioned above. As such, it may be appropriate to conduct each of the studies. However, it is necessary that the first study be conducted in some reasonable fashion before the study corresponding to step 2 could be fruitful. Similarly, a reasonable effort addressing both the problems corresponding to steps 1 and 2 is required before a study addressed at step 3 could be expected to provide significant insight.

5.1 Structuring Manpower Planning Objectives

None of the existing studies have made a serious attempt to relate the main objectives of manpower planning to the attributes over which the utility functions are to be assessed. This should be an important part of any application of utility theory. It is suggested that it would be very worthwhile to structure the objectives of naval manpower planners.

A reasonable starting point for such a study would be to obtain or develop a clear definition of the force objectives of the Navy. It may be the case that the study could be done for a segment of the Navy, in which case the objectives should correspond to that segment. The first task would be to relate the manpower planning objectives to those force objectives. The process for doing this must inherently use professional judgments. A concept which may be helpful would involve the separation of the value of particular positions in the force from the value associated with the level of performance of those positions. This would correspond then to a concept that the optimal force would involve individuals in each of the positions providing an optimal level of effort. In any overall optimization, constraints on the necessary progress of individuals through the force and the learning times involved in each position will then contribute to less than optimal performance at each of the stated positions. Such considerations will obviously be included in evaluating any policies affecting the desirability of the force.

Once a reasonable objectives hierarchy of manpower planning objectives is structured, it will be necessary to carefully articulate attributes for each of the lowest-level objectives. The specification of any objective requires value judgments. Normally these value judgments are implicit, and sometimes they are not even evident to those using the analyses. Significant care must be taken in this specification of attributes to insure that the inherent value judgments are appropriate for the problem being addressed.

An important issue in conducting this research will be whose objectives are important. It would seem appropriate to begin the process dealing with a few (four or less) individuals with the responsibility for making personnel decisions. The initial structuring of objectives would provide a useful basis on which to improve if further improvement or efforts seem worthwhile. If this initial structuring seemed helpful, the effort could be expanded to include individuals in different posi-

tions within the Navy. Specifically, individuals with different experience concerning the problem being addressed should be utilized.

The resulting objectives hierarchy and attributes can be utilized mainly as an information and communication device. It can provide a basis for constructive discussions and the resolution of any conflicts between different individuals concerned with the problem. The set of attributes should serve as a foundation for assessing the utility function. The end result should also significantly lessen the likelihood that double-counting of any sort is included in the evaluation of alternatives once a utility function is assessed.

5.2 Structuring and Assessing the Utility Function for Manpower Planning

Once the objectives hierarchy and attributes are specified, a utility function could be carefully assessed over these attributes. These assessments should be conducted individually. At first, I would utilize three or four individuals in the Bureau of Naval Personnel for assessments. The assessments should concentrate on verifying an appropriate value structure for the problem. This would involve the verification of different value assumptions felt to represent accurately the values of the individuals being assessed. Significant effort should be involved in consistency checks to ensure that the value structure is appropriate. In cases where value dependencies are identified, effort should be expended to identify the sources and reasons for these dependencies. This might result in modifications to the original objectives hierarchy. In this sense, the structuring and assessment of the utility function interacts in a complicated way with the defining of the objectives hierarchy.

Once a general structure of the utility function is available, the value parameters should be carefully assessed. These parameters would address the value tradeoffs between the various attributes and the attitudes toward risk for each of the attributes. The procedures utilized should follow those outlined in great detail in references such as Keeney

and Raiffa [1976]. The assessment process should also have a number of consistency checks to insure that the stated preferences represent the individual's value judgments. After individual utility functions are obtained for three or four individuals, it should be possible to identify any conflicts among them. These conflicts would exhibit themselves by the presence of significantly different values for the value parameters. This should focus a discussion to provide a better understanding about why various attribute levels have specific values. This process will also help suggest a means to reconcile the conflicts. The end result might be one utility function that is acceptable to each of the individuals involved.

One of the items to which particular attention must be paid in the assessments is the meaning of utility. That is, what is being measured by the utility. Is it the value of a particular position in the naval force, is it the value of a particular performance in that position, is it the increase in value of a particular performance in that position relative to the performance of an uninitiated individual, or what? It must be very clearly specified in all the utility assessments exactly what it is that the utility is meant to capture. This not only aids the assessees in their thinking, but it also significantly improves the communication process and helps in providing insights to what may be better alternatives.

Once a reasonable objective is obtained for individuals in the Bureau of Naval Personnel, it may be appropriate to repeat the structuring and assessment of the utility functions for other individuals concerned about a specific problem. This step in the second research project would parallel a step of the first project above. As before, we would expect interaction between the structuring and assessment steps and the definition of the objectives hierarchy. It would be insightful to compare the utility functions of naval personnel planners and other individuals with responsible positions in the Navy concerned about specific personnel

problems. To the extent that there are serious discrepancies, the utility functions could provide a basis to better understand these and alleviate difficulties caused by the differences.

Once we have iterated a few times with this procedure, an agreed upon representative utility function may emerge. This utility function would be meaningful for evaluating alternatives for a base case evaluation. It would clarify what attributes were important and why. Furthermore, the assumptions made in developing the utility function would be explicit and justified, and hopefully justifiable to others. In sensitivity analyses, the value parameters could be verified to represent points of view of different individuals if in fact these differences seemed significant. The sensitivity analyses would indicate in fact whether or not those perceived differences were significant.

5.3 Evaluation Using the Utility Function

The third research project would involve the evaluation of various alternative manpower options using the resulting utility function. This should be done recognizing that the utility function is only preliminary. As a result of these evaluations, it should be possible to identify which value judgments are critical to the overall evaluation of manpower options. These would be identified by conducting a sensitivity analysis. For these judgments, it may then be appropriate to expand the base of individuals from whom the judgments were assessed. This process could be conducted more thoroughly and clearly than the initial studies because the meanings of the attributes could be more carefully defined. Furthermore, because there would likely be fewer value judgments on which to focus, it would be more likely that careful attention on those value judgments would be provided by individuals being assessed.

If all three research studies were conducted, it would be possible to understand why particular personnel options were evaluated higher than others. This understanding is in fact a key result of utility analysis.

This understanding, together with information exogenous to the model being utilized, is necessary to make responsible personnel decisions. Never is it the case that the personnel model is a substitute for the decision makers on such complex problems. However, only when each of the three steps mentioned at the beginning of this section are carefully conducted is it likely that the full value of utility theory can be utilized to help the decision makers.

5.4 Summary

Manpower and personnel planning is a significant problem in the Navy or any large organization. The consequences of the alternative policies selected are important. The desirability of the options can only be indicated by considering how well the options will likely perform in terms of the objectives to be achieved. Most traditional manpower and personnel planning models have not carefully focused on those objectives. The utilization of utility theory for structuring objectives and quantifying an objective function has much to offer. However, for the potential advantages to be achieved, the research must be carefully and thoroughly conducted. The theory is sound and operational procedures are available for the task. However, it is not easy to utilize, and its application requires substantial creativity. This is due to the inherent complexity of the problem, rather than shortcomings of the approach. To date, thorough attempts to quantify value judgments appropriate for naval personnel planning have not been conducted. Because of the importance of the problem and the potential advantages involved, it seems worthwhile to attempt such a research project.

REFERENCES

Arrow, K.J. (1951) (2nd ed. 1963). Social Choice and Individual Values. Wiley, New York.

Bell, D.E. (1979). Consistent assessment procedures using conditional utility functions. Operations Research, 27, 1054-1066.

Bell, D.E. and H. Raiffa. (1979). Marginal value and intrinsic risk aversion. HBS 79-65, Graduate School of Business Administration, Harvard University, Boston, Mass.

B-K Dynamics, Inc. (1973). Development of utility measures for manpower planning. TR-3-177, Rockville, Maryland.

Brown, R.V., A.S. Kahr, and C.R. Peterson. (1974). Decision Analysis for the Manager. Holt, Rinehart and Winston, New York.

Campbell, V.N., M.F. O'Connor, and C.R. Peterson. (1976). Accrued utility of navy enlisted personnel. Decisions and Designs, Inc., McLean, Virginia.

Dyer, J.S. and R.K. Sarin. (1979). Measurable multiattribute value functions. Operations Research, 27, 810-822.

Farquhar, P.H. (1977). A survey of multiattribute utility theory and applications. In Multiple Criteria Decision Making, M.K. Starr and M. Zelany (eds.), North Holland, Amsterdam.

Fishburn, P.C. (1964). Decision and Value Theory. Wiley, New York.

Fishburn, P.C. (1965). Independence in utility theory with whole product sets. Operations Research, 13, 28-45.

Fishburn, P.C. (1970). Utility Theory for Decision Making. Wiley, New York.

Fishburn, P.C. (1973). The Theory of Social Choice. Princeton University Press, Princeton, NJ.

Fishburn, P.C. (1977). Multiattribute utilities in expected utility theory. In Conflicting Objectives in Decisions, D.E. Bell, R.L. Keeney, and H. Raiffa (eds.), Wiley, Chichester, England.

Harsanyi, J.C. (1955). Cardinal welfare, individualistic ethics, and interpersonal comparisons of utility. Journal of Political Economy, 63, 309-321.

Horowitz, S.A. and A. Sherman. (1977). The characteristics of naval personnel and personnel performance. Center for Naval Analysis, Arlington, Virginia.

Jaquette, D.L., G.R. Nelson, and R.J. Smith. (1977). An analytical review of personnel models in the Department of Defense. R-1920-ARPA. The Rand Corporation, Santa Monica, CA.

Keeney, R.L. and C.W. Kirkwood. (1975). Group decision making using cardinal social welfare functions. Management Science, 22, 430-437.

Keeney, R.L. and H. Raiffa. (1976). Decisions with Multiple Objectives. Wiley, New York.

Keeney, R.L. (1980). Measurement scales for quantifying attributes. Woodward-Clyde Consultants, San Francisco, CA.

Koopmans, T.C. (1960). Stationary ordinal utility and impatience. Econometrica, 28, 287-309.

MacCrimmon, K.R. (1969). Improving the system design and evaluation process by the use of trade-off information: an application to northeast corridor transportation planning. RM-5877-DOT. The Rand Corporation, Santa Monica, CA.

Miller, J.R., III. (1970). Professional Decision Making. Praeger Publishers, New York.

Pratt, J.W. (1964). Risk aversion in the small and in the large. Econometrica, 32, 122-136.

Raiffa, H. (1968). Decision Analysis. Addison-Wesley, Reading, Mass.

Raiffa, H. (1969). Preferences for multi-attributed alternatives. RM-5868-DOT/RC. The Rand Corporation, Santa Monica, CA.

Sackman, H. (1974). Delphi assessment: expert opinion, forecasting, and group processes. R-1283-PR. The Rand Corporation, Santa Monica, CA.

Savage, L.J. (1954). The Foundations of Statistics. Wiley, New York.

Schlaifer, R.O. (1969). Analysis of Decisions Under Uncertainty. McGraw-Hill, New York.

Schmid, J.R. and R.K. Hovey. (1975). Utility theory and optimization in military personnel management. TR-3-138. B-K Dynamics, Inc., Rockville, MD.

Sen, A.K. (1970). Collective Choice and Social Welfare. Holden-Day, San Francisco, CA.

von Neumann, J. and O. Morgenstern. (1947). Theory of Games and Economic Behavior. 2nd ed. Princeton University Press, Princeton, NJ.

APPENDIX A

AN OVERVIEW OF MANPOWER PLANNING ANALYSES*

The output of any productive unit can be expressed as some function of its inputs, capital (K) and labor (L). The objective of the productive unit is to maximize output subject to a cost or budget constraint. This level of output is achieved at the point where the marginal product of a dollar's worth of labor is just equal to the marginal product of a dollar's worth of capital. Or stated differently, the point of maximum output is obtained when the ratio of the marginal products of the inputs is equal to the ratio of input prices. Letting MP_K and MP_L stand for the marginal products of capital and labor, respectively, and P_K and P_L represent the respective input prices, the point of maximum output is defined as that point where $MP_K/MP_L=P_K/P_L$. The assumptions of this model include perfect information as to input prices and perfect freedom to substitute labor for capital and vice versa.

When we talk about the marginal product of capital and the marginal product of labor we are referring to that addition to total output that can be attributed to the last unit of capital or labor added to the productive process. The relationship between units of inputs, resulting outputs and cost is often depicted as shown in Figure A.1 below.

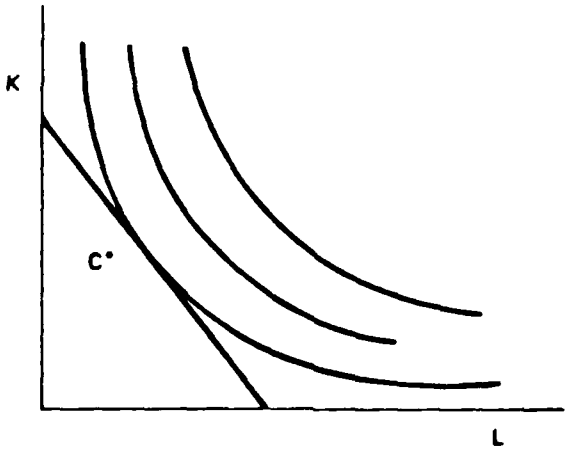


Figure A-1. PRODUCTION POSSIBILITIES

*This appendix was written by Patricia D. Fleischauer.

Each curve represents a different amount of total output. Each point along any one curve is the amount of capital and amount of labor necessary to achieve that level of output. For a budget constraint C, that assumed known prices for K and L, the optimal level of production is at point C*.

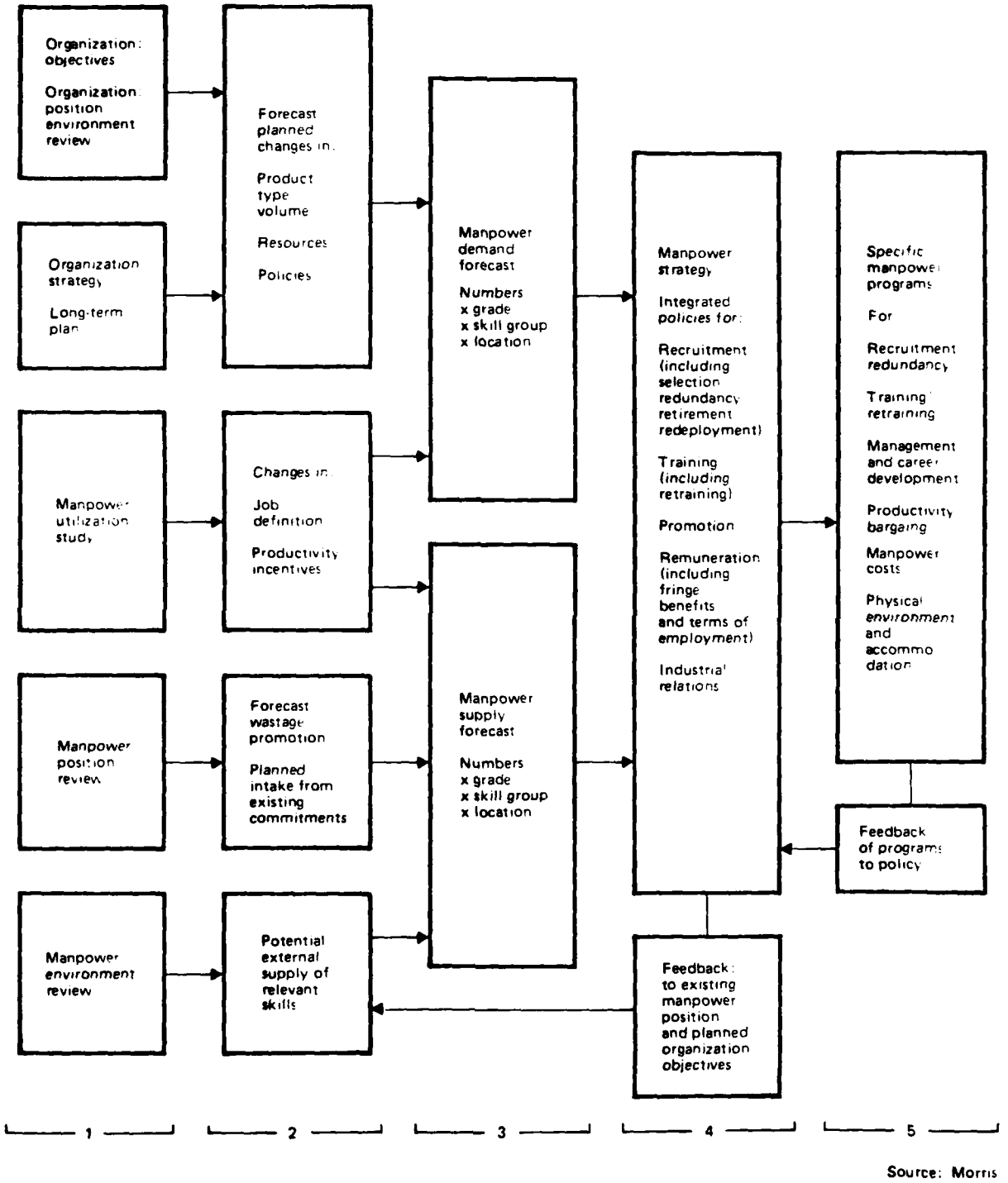
We say all of this not for purposes of a quick review of economics, but by way of placing in a framework the problem of military manpower and personnel planning. Some of the departures from this simple model which have plagued planning efforts are the following:

1) the absence of a price for the output;

2) a closed personnel system that takes in relatively inexperienced personnel and then trains them; one that has virtually no lateral entry and hence is limited in its ability to substitute among inputs;

3) a system, that by virtue of rewards being related to length of service, forces people out of positions they are best at and moves them to positions, usually supervisory, where they may be less effective, less productive.

One way of viewing the whole of the manpower and personnel planning process is shown in Figure A.2. In this approach to manpower and personnel planning, manpower utilization is at the very beginning of the planning process and hence intimately related to many of the efforts that follow. In particular, considerations of manpower utilization precede both questions of manpower supply and manpower demand. While numerous studies have addressed these latter two questions, a review of manpower and personnel research to date shows that until recently productivity studies have been noticeably absent. While there was much concern for example with the supply of manpower in the environment of an all volunteer force, there



Source: Morris

Figure A-2. COMPONENTS OF MANPOWER AND PERSONNEL PLANNING

were no parallel or prior studies of manpower productivity. It is only in the past few years, with the work on the Navy ADSTAP Model[1] and some of the work done for DARPA at the Rand Corporation[2], that an attempt has been made to address such issues in the context of manpower and personnel planning. The success of some of these endeavors has been challenged. Indeed, the purpose of this study is to review this assessment of utility and suggest the role of utility theory in manpower and personnel planning.

The absence of prior consideration of utility or productivity does not negate work to date. Much of that work was basic research and development and testing of methodologies which had value in and of themselves. Where there have been shortcomings, they have been with those models that have attempted some sort of optimization. Clearly, the absence of measures of productivity calls into question the results of prior optimization studies. But optimization studies are only one part of the manpower and personnel planning literature. Indeed, this literature has grown so fast that in the early 1970's, when the Navy undertook a review of the literature, they found some 200 studies to consider.[3] In 1976, Nelson and Jaquette

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[1]Lehto, Robert, et al., The U.S. Navy Enlisted Force Management System: The ADSTAP Master System (Second Interim Report), Bureau of Naval Personnel, Washington, D.C., June 1973. Silverman, Joe, New Concepts in Enlisted Personnel Planning: Introduction to the ADSTAP System, Naval Personnel and Training Research Laboratory, SRR 71-28, San Diego, CA, May 1971.

[2]Gay, Robert M., Estimating the Cost of On-the-Job Training in Military Occupations: A Methodology and Pilot Study, The Rand Corporation, R-1351, Santa Monica, CA, April 1974. Cooper, Richard V.L. and Gary R. Nelson, Analytic Methods for Adjusting Subjective Rating Schemes, The Rand Corporation, R-1685, June 1976. Gay, Robert M. and Mark J. Albrecht, Specialty Training and the Performance of First-Term Enlisted Personnel, The Rand Corporation, R-2191, April 1979.

[3]Hutchins, E.S., Jr., et al., Computer Models for Manpower and Personnel Management: State of Current Technology, WTR 73-25, Naval Personnel Research and Development Laboratory, Washington, D.C., April 1973.
_____, Computer Models for Manpower and Personnel Management: State of Current Technology, Appendix A-Compendium of Models and Related Manpower/Personnel Programs and Studies, WTR 73-25A, Naval Personnel Research and Development Laboratory, Washington, D.C., April 1973.

undertook an additional review.[4] They found 26 studies that met their criteria and screened out all those that were deficient, poorly specified and relatively undocumented. In total, the amount of work done has been tremendous, enough to warrant several critical reviews and enough that we have probably sufficiently refined such computational techniques as linear programming. The work has also been enough that we have probably answered the easy questions and now must deal with the difficult ones. We are also at a point where we can usefully identify what has been done and what has not been done.

Without reviewing here all past modeling efforts, we can summarize these as generally falling into areas 3, 4 and 5 in Figure A.2. The approaches taken have varied. These we will review for the purpose of making clear what assumptions have been made, either explicitly or implicitly, and to point out what assumptions about productivity were implied or assumed. There are three basic distinctions that we consider in reviewing manpower and personnel planning to date:

1) the type of data used--cross-sectional or longitudinal;
2) optimization versus nonoptimization, such as simulation;
3) stochastic versus deterministic.

We look at these three aspects because of the assumptions about productivity.

Type of Data Used. In talking about type of data used, we are immediately asking about the modeling approach used. Was the model built from the top down, or from the bottom up?

In a model using cross-sectional data, almost surely the approach followed was from the top down. At some single point in time, a snapshot

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[4] Jaquette, D.L., G.R. Nelson and R.J. Smith, An Analytic Review of Personnel Models in the Department of Defense, The Rand Corporation, R-1920, September 1977.

was taken of the force, and it was then disaggregated as believed necessary to address the problem at hand. Without worrying about when this snapshot was taken, let us see what this means in terms of analyzing a firm or a unit's productivity. For example, we take snapshots on June 15 for five straight years and note the following:

Unit output
Equipment used in production
Number of supervisory personnel
Number of personnel of type A
Number of personnel of type B, etc.

Making the appropriate calculations, we could make some general comments about the relative contributions of labor and capital to output. What has been assumed in these snapshots and in our calculations is perfect interchangeability and substitutability among personnel. The number of each type of personnel, A and B, is all that matters, not how they got to be A's or B's. Stated simply, one's position at a point in time summarizes all that is known and needs to be known. This is a strong assumption but one that can provide a reasonable state for a model; in reality, however, it is often violated.

The simplicity of the cross-sectional approach is contrasted with the data intensive longitudinal or bottom up approach. Again looking at firm or unit productivity over a five year period, this approach would begin by constructing a time series of data. Using personnel records, it would attempt to track each individual over time, considering such things as age, previous experience, education, and most importantly, time in each position. While such an approach has intimate concern with the unique aspects of individuals, it usually fails to integrate these in a way useful to planners. Typically, it cannot abstract from the collection of individuals that combination which made the team of which they were all a part so successful. Particularly for the military planner, the

output of these exercises is hard to interpret. The military does not hire for a particular position; rather they recruit in large numbers and train according to quotas that may or may not produce the specific set of characteristics that would result from a longitudinal data based model.

Optimization versus Nonoptimization. Absent an objective function, manpower and personnel planning models can be basically flow description models. They can either move forward, ageing the force as it were, to investigate the future impact of various pay and promotion policies, or they can move backward from an ideal end point to show what needs to be done with the current force in order to achieve this desired end. Implicit in such simulations is the decision maker's objective function. Clearly, such exercises aid in policy analysis and in many cases involve objectives that are difficult to quantify. Unfortunately, difficult to quantify often means unexplained, and so the models lose their use as soon as their developers are finished with the model.

Optimization models, while often only flow models complicated by an objective function and constraints, at least allow assessment by an outsider if they are familiar with linear programming. Given the dearth of productivity measures, it is hard to estimate the usefulness of such models which are at best selecting the appropriate amount of defense for a budget that is stated in numbers of slots, not dollars.

Optimization models are typically future oriented. Inputs therefore are filled with assumptions about the future. As for productivity, there is often little to base future estimates on, and traditional manpower levels are assumed. In the absence of other information, this is a conservation posture and one that ignores changes in technology as well as the changes in individuals, which over time result in a once productive group becoming relatively unproductive or vice versa. There is substantial literature documenting productivity changes, for example, as a result of women's entry into various previously male-dominated occupations.

Stochastic versus Deterministic. The contrast in these approaches is quite clear. The deterministic model relies on the past as a predictor of the future. The stochastic model, on the other hand, recognizes the uncertainty about the future and makes some provision for dealing with it. For example, in progressing from personnel position type B of our earlier example to personnel position type A, a deterministic model would take these calculated transition probabilities and apply them to any new set of numbers to estimate numbers of personnel in the next time period. The stochastic model would attach a probability distribution to each transition probability and sample from this in estimating personnel in the next period.

The stochastic model, insofar as productivity is concerned, is no doubt the more realistic. We know that team behavior is a function of individual synergy, response to environment, personal health and well-being as well as group organization. Hence, one point in time estimate of productivity cannot be taken as absolute.

Having made the case for the need to consider productivity, we should recognize that problems still lie ahead even if and when we do incorporate it in manpower and personnel planning. For one, some parts of the system, or even the whole, are not really testable. Second, technology is probably changing faster than we can change the personnel system to keep up with it. We like to think of man as infinitely adaptable, but every aptitude test ever given has shown that some of us are better with our hands than others, some stronger, some better thinkers. Uniform physical standards as practiced certainly assure us one kind of flexibility, but no doubt at the expense of other kinds of talent. Lastly, we have notions in our management of personnel that run counter to notions of productivity. In the classical model we first discussed, the optimal level of output was at the point where $MP_K/MP_L=P_K/P_L$. In the military system, achievement of this level of output is constrained by our notion of equity which results in equal pay for equal years of service, and this is not necessarily related to productivity.

APPENDIX B

BRIEF SURVEY OF "THE CHARACTERISTICS OF NAVAL PERSONNEL AND PERSONNEL PERFORMANCE"

The work by Horowitz and Sherman [1977] was not conducted to determine a utility function. The general problem was to contribute to an understanding of how personnel relates to the effectiveness of the naval fleet. Since the spirit of this problem is the same as that addressed by the utility approaches discussed in Chapters 3 and 4, it appears worthwhile to review briefly the approach taken.

The problem was to identify how various crews, as opposed to individuals, contributed to the effectiveness of the fleet. The specific problem of focus concerned the relationship between crews and downtime of particular pieces of equipment such as boilers and missiles. These relationships were to be identified using regression analysis. Data from the period 1967 to 1975 was obtained for a number of ships to indicate the characteristics of the crew manning particular systems (such as boilers) and the reported downtime of those systems.

The crew was categorized by several variables. These were the following: number of enlisted personnel, pre-Navy education, entry test scores, paygrade profile, length of service, time aboard this ship, time at sea, Navy schooling, specialized qualifications, race, and marital status. Downtime was defined as the total amount of time during which specific equipment failure degraded the operational capability of that equipment. Such downtime is to be reported in the reporting system used by the Navy. These records were used to collect the data.

The regression analysis, using the linear least-squares method, was to relate variations among the level of maintenance in different ships to the differences in the crews responsible for this maintenance. If such a link could be identified, it could have significant implications for

personnel policies. The study did show significant relationships for some of the personnel variables for some specific systems. However, no complete systems were addressed in this paper. What Horowitz and Sherman did is indicate a potentially useful approach for investigating some significant relationships between personnel and downtime of shipboard equipment.

From the perspective of utility theory, one can think of the model developed by Horowitz and Sherman as a consequence model. That is, for any particular policy that may affect personnel, one can determine the effect on downtime. It may be useful to assess a utility function over downtime of the various pieces of equipment and combine this with the Horowitz and Sherman model for examining personnel policies. If such a process were carried out, one further step may seem reasonable. This is to attempt to relate downtime of equipment to the overall effectiveness objectives of the fleet. There is likely much to be learned about the relationship between downtime and fleet effectiveness. This may be significant for affecting the specific utility function for downtime, and hence the evaluation of personnel policies using downtime. The Horowitz and Sherman study would be complementary to a thorough specification of objectives and resulting quantification of a utility function.

APPENDIX C

THE LITERATURE SEARCH

A literature search was conducted to identify work in manpower planning using utility theory. Aside from references in the well-known technical journals and books concerning utility theory or manpower planning, several citation lists were requested from S.D.C.'s International Search Service. Five individual searches were performed. These were the following:

1. A search on the National Technical Information Service using the pair of key words utility theory and management (20).

2. A search of the National Technical Information Service using the pair of key words utility theory and models (83).

3. A search on Social Scisearch using the key word manpower planning (55).

4. A search on conference papers using the pair of key words utility theory and management (11).

5. A search on Social Scisearch using the key word utility theory (21).

The number of references provided in each search is given in parenthesis.

Based on a careful appraisal of many of these sources, we concluded that the main efforts involving the use of utility theory and manpower planning are those by B-K Dynamics, Inc. discussed in Chapter 3 and by Decisions and Designs, Inc. discussed in Chapter 4.

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The personnel management and manpower planning problems of the United States Navy include complex value structures with no obvious external criterion for examining alternative courses of action. Recognizing this, the Department of the Navy has sponsored studies of the applicability of utility theory to the personnel management and manpower planning problems of the Navy. The purposes of this project are to review and appraise such efforts and to recommend further work using utility theory to assist the navy on manpower problems. It is concluded that the previous applications had numerous

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unnecessary shortcomings. The specific problems addressed were not clearly defined, and appropriate procedures to assess utility were not used. However, recommended applications of utility theory to manpower problems have the potential for significant contributions.